The ADEPT Group, Inc.

Services at the interface of energy, economics and environment

1575 Westwood Blvd., Suite 200, Los Angeles, CA 90024 USA Telephone (310) 478-8448 Fax: (310) 478-5658

file: ARBMR001a June 17, 1998
SCAQMD Contract No: 98108

ARB LPG Fuel Blends Evaluation Project
April 1998 Progress Report

submitted to:

ARB LPG Fuel Blends Evaluation Project Task Group

American Automobile Manufacturers Association, ARCO Products Company, California Air Resources Board, Cummins Engine Company, Engine Manufacturers Association, Equilon, Ford Motor Company, GFI, IMPCO, National Propane Gas Association, Natural Resources Canada, Railroad Commission of Texas Alternative Fuels Research & Education Division, South Coast Air Quality Management District, Western States Petroleum Association

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I. Executive Summary

The fuel blends were shipped to two laboratories. ORTECH Corporation (ORTECH), with support from Cummins Engine Company (Cummins), conducted test cell preparation, engine conditioning, and engine calibration and troubleshooting. Dixie Services, Inc. (Dixie) commenced fuel speciation tests. ADEPT submitted several funding proposals, prepared contracts and provided support to project subcontractors.

II. Test Program Work Performed

A. Fuel Delivery to Current Subcontractors

Dixie received the fuel blends from Aeriform on April 15, 1998. ORTECH received the fuel blends on April 29, 1998. Delivery of the fuel to ARB's Haagen Smit Laboratory in El Monte, California (ARB-El Monte) is expected in mid-May.

B. Fuel Properties and Octane Testing

During the March 26th Task Group conference call, its members recommended further evaluation of which test methods Dixie is to use: (a) those recommended by Dixie in their quote; or (b) those specified in the California Code of Regulations and cited in the ARB January 1997 report. The noted differences between the two protocols were; (1) water content, and (2) sulfur. Dixie also recommended that a fluoride content test be conducted to further validate the octane number results. ARB staff solicited feedback from each Technical Committee member. It was decided to proceed with the following protocol:

Specification	Value	Test Method
Propane – Gas Chromatography	vol.%	ASTM D 2163
Vapor pressure at 100 °F	Psig (max)	ASTM D 2598
Volatility residue	°F at 95% evaporation	ASTM D 1837
Residual matter	0.05 ml	ASTM D 2158
Corrosion, copper strip	No.1	ASTM D 1838
Sulfur	ppm	ASTM D 3246[1]
Moisture Content	pass	ASTM D 2713
Fluoride	ppm	UOP 619[2]

As of the end of April, Dixie received the fuel blends and began testing.

C. Medium-Duty Engine (Cummins B5.9LPG) Emissions Tests at ORTECH.

ORTECH began the test cell set up and preparation. In the conduct of engine commissioning ORTECH defined the engine's performance parameters for testing. In consultation with Cummins the below parameters were established:

- Intake restriction 4.4kPa (17.5" H_20)
- Exhaust back pressure 13.5 kPa (4.0" Hg)
- Intake manifold temperature 52°C (125°F)
- Air pressure drop from the compressor outlet to the mixer inlet 13.5 kPa (4"Hg)

The tested engine performance plot is as follows[3]:

	Speed (rpm)	Torque (lb-ft)	Power (bhp)	Variation from Specification
Rated Power	2,600	411	203	+4.1%
Peak torque	1,600	444	135	+5.5%

A transient cycle regression analysis was conducted to determine how well this engine follows the transient emissions test cycle. It verified that the engine is able to pass cycle regression criteria with 20 lb-ft and 10 lb-ft of curb idle transmission torque.

[1] ASTM D 3246 was selected in place of ASTM D2784 due to two reasons given by Dixie: (1) it is slightly more accurate and (2) it is repeatable.
[2] Universal Oil Products (UOP) Test #619 was added to the protocol. It is the only company that has a specified flouride test.
[3] See ORTECH engine daily performance check and ECU voltage analysis in appendices for further detail regarding day-to-day variability in engine performance and emissions (April 15 & 17).

Unforeseen issues arose. These were:

- It initially appeared that the engine was calibrated at slightly higher horsepower and torque. After suitable calculations this calibration was found to be within 5% of rated specifications. The engine was determined to be suitable for further tests.
- Engine power, torque and emissions were sensitive to: (a) ECU[4] supply voltage, and (b) throttle sensitivities.

Preliminary engine emission tests were conducted on bulk HD-5 LPG (propane 96%, ethane 4%, air DL, butane DL). At an ECU supply voltage of 12.3 volts emissions results were as follows:

		Value = g/bhp/hr		
Cycle	Run #	**NOx**	**THC**	**CO**
Cold cycle	900	2.549	1.633	0.600
Hot cycle #1	901	2.382	0.969	0.199
Hot cycle #2	902	2.405	1.079	0.168

ORTECH continued calibration and tuning of the dynamometer as well as it began quality control setup and preliminary sample range setup on the gas chromatography (GC) analyzer for fuel specificiation analysis verification. Some unexpected problems occurred with the GC analyzer.

ORTECH received the fuel blends on April 29. On April 30th ORTECH verified the labels on the LPG blends cylinders. A fuel blend label indicated that one blend was outside the ADEPT requested specs.

No further engine tests were conducted in April.

D. Light-Duty Truck (F150 Bi-Fuel) Emissions Tests at ARB Haagen Smit Laboratory

The Ford vehicle was undergoing testing in another program. It has not been delivered to ARB El-Monte. Ford indicated that if the F150 is not available in time their next option was the F250 bi-fuel truck. ARB-El Monte staff expressed concern in that the F250 is not classified as a light-duty truck. ADEPT and WPGA made back-up arrangements to secure another F150 truck. Ford is to notify ARB/ADEPT in early May as to the F 150's availability and delivery date.

E. Performance and Combustion and Durability Tests

The following laboratories are to receive a request for proposal: Cummins, Southwest

[4] ECU – electronic control unit

Research Institute (SwRI), University of California at Riverside Research Center (CE-CERT), and ORTECH. Initial proposal-solicitation discussions and/or drafts were conducted with all laboratories.

II. Project Management Support and Administrative Work Performed

A. Project Fundraising

ADEPT submitted funding proposals to the Engine Manufacturers Association (EMA), Exxon and Tosco. The proposal to EMA was to further support existing Cummins contributions to the project.

B. Project Expenditures

The table below shows April expenditures, as approved during the March 26, 1998 Task Group meeting, and total expenditures to date.

Item	Funds Expended In April	Total Funds Expended
Fuel (Aeriform)	$0	$3,000
Emissions Tests (ORTECH)	$27,000.00	$42,000
Fuel Properties (Dixie)	$0	$0
ADEPT P.M.	$0	$0
Attorney Fees	$2,187.50	$2,187.50
Subcontractor	$312.50	$630.75
Total	29,500.00	$47,818.25

Project Account Balance: $7,978.97
Outstanding invoice(s): $90,000 Canadian from PGAC/NRCan

Total funds received to date, by funder source are:

Funder	Amount
NPGA	$9,000
Shell	$36,000
WPGA	$10,000
Total	$55,720

C. Project Contracts and Other Documents

ADEPT finalized fuel purchase orders with Aeriform. ADEPT prepared and submitted support documents for the SCAQMD contract and submitted a draft letter of agreement for ARB's review. ADEPT solicited outstanding signatures for the MOU. As of April 30th, outstanding MOU signators are: AFRED, ARB, Cummins, and NPGA.

Travel associated with effort described:.
No travel was conducted.

II. Work planned for the next reporting period (May 1 - 31, 1998)

Project Management-ADEPT

1. ADEPT will continue general project management.
2. ADEPT will prepare and complete funding contracts and letters of agreement for co-sponsors.
3. ADEPT will continue fundraising.
4. ADEPT solicitation of proposals for performance/combustion tests.
5. ADEPT solicitation of proposals for durability tests.

Test Program

1. ORTECH: Begin emissions testing.
2. Dixie: Conduct and complete fuel speciation and octane tests.
3. Aeriform: Deliver fuel to ARB/El Monte Laboratory.
4. Receive pre-proposals for performance, combustion tests.
5. Receive pre-proposals for durability tests.

III. Attachments:

1. Project Timeline (GANTT Chart).
2. ORTECH Weekly/Interim reports: April 6, April 13, April 15, April 17, April 20, and April 27 (with mailed version).

IV. Disclaimer

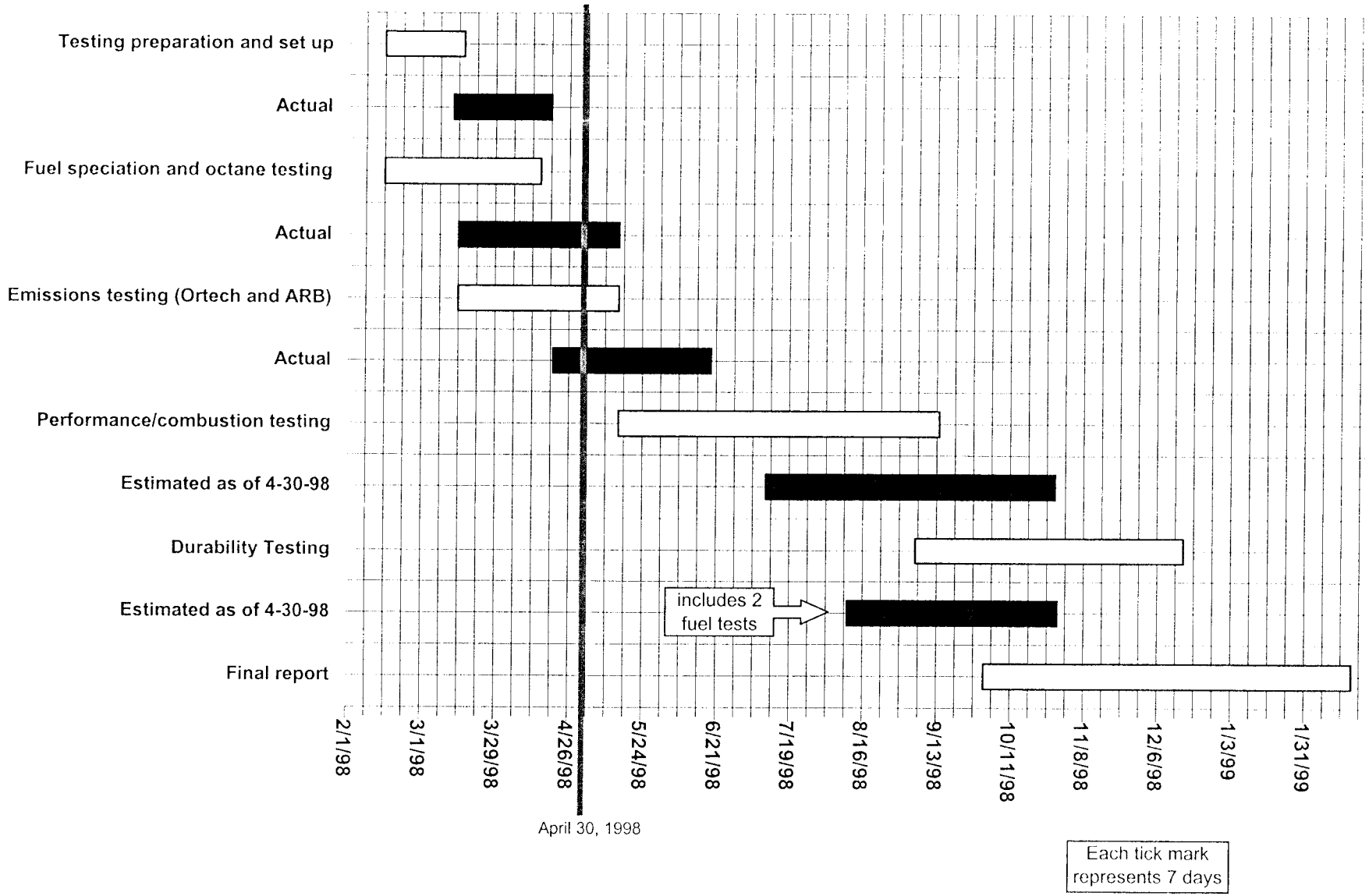
This report was prepared by The ADEPT Group, Inc. (ADEPT) as a result of work co-sponsored by the South Coast Air Quality Management District (SCAQMD) and Task Group Members. The opinions, findings, conclusions, and recommendations are those of the author and do not necessarily represent the views of SCAQMD. SCAQMD, their officers, employees, contractors, and subcontractors make no warranty, expressed or implied, and assume no legal liability for the information in this report. SCAQMD has not approved or disapproved this report, nor have they passed upon the accuracy or adequacy of the information contained herein.

V. Glossary of Acronyms

ARB	California Air Resources Board
ASTM	American Society for Testing and Materials
bhp	brake horse power
C	celsius
ECU	electronic control unit

EMA	Engine Manufacturers Association
F	fahrenheit
g/bhp/hr	grams/brake horse power/hour
Hg	mercury
kPa	kilopasquals
lb.-ft.	pound feet
LPG	liquefied petroleum gases
psig	pounds per square inch of gas
ppm	parts per million
rpm	revolutions per minute

ARB LPG Fuel Blends Evaluation Project Milestone Chart



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ORTECH

PROGRESS REPORT

Date: 4/6/98
Report: #3, Period: 98/03/30 to 98/04/05
ADEPT / Cummins B5.9 LPG

Attn: Mr. Alex Spataru

To: Mr. Alex Spataru

Client: ADEPT Group Inc.
Project: **ADEPT / Cummins B5.9 LPG**
Tel: (310) 478-8448
Fax: (310) 478-5658
ADEPT P.O.: Date: March 2,1998, Value: US$141,350
ORTECH Ref: Project No.: 1-05-01-01-11516
Proposal No.: 97-1-05-01-01-P8138-FI

Submitted by: Dr. Aurobindo Das
Telephone: (905) 822-4111 (X418)
Fax: (905)823-1446

Estimated Testing Completion Date: To be determined
Estimated Project Expenditure to 98/04/05: US$24,100
Estimated Expenditure for Last Week (Mar. 30-Apr.05): US$4,400
Estimated Cost at Completion: To be determined
Initial Payment received: US$15,000
Invoiced to date:
Invoice details:
Received to date:

Activities/Tasks Conducted
Period: 98/03/30 to 98/04/05

1. The following items were completed:
- In-line torque meter and drive line bearing repair
- Dynamometer speed sensor and torque meter calibration
- Engine commissioning on HD5

2. A engine torque curve was generated on HD5 for performance confirmation. The parameter setup was:
- intake restriction 4.4 kPa (17.5"H_2O)
- exhaust back pressure 13.5 kPa (4.0"Hg)
- intake manifold temperature 52°C (125°F)
- air pressure drop from compressor outlet to mixer inlet 13.5 kPa (4"Hg).

The engine performance was summarized with plot attached:

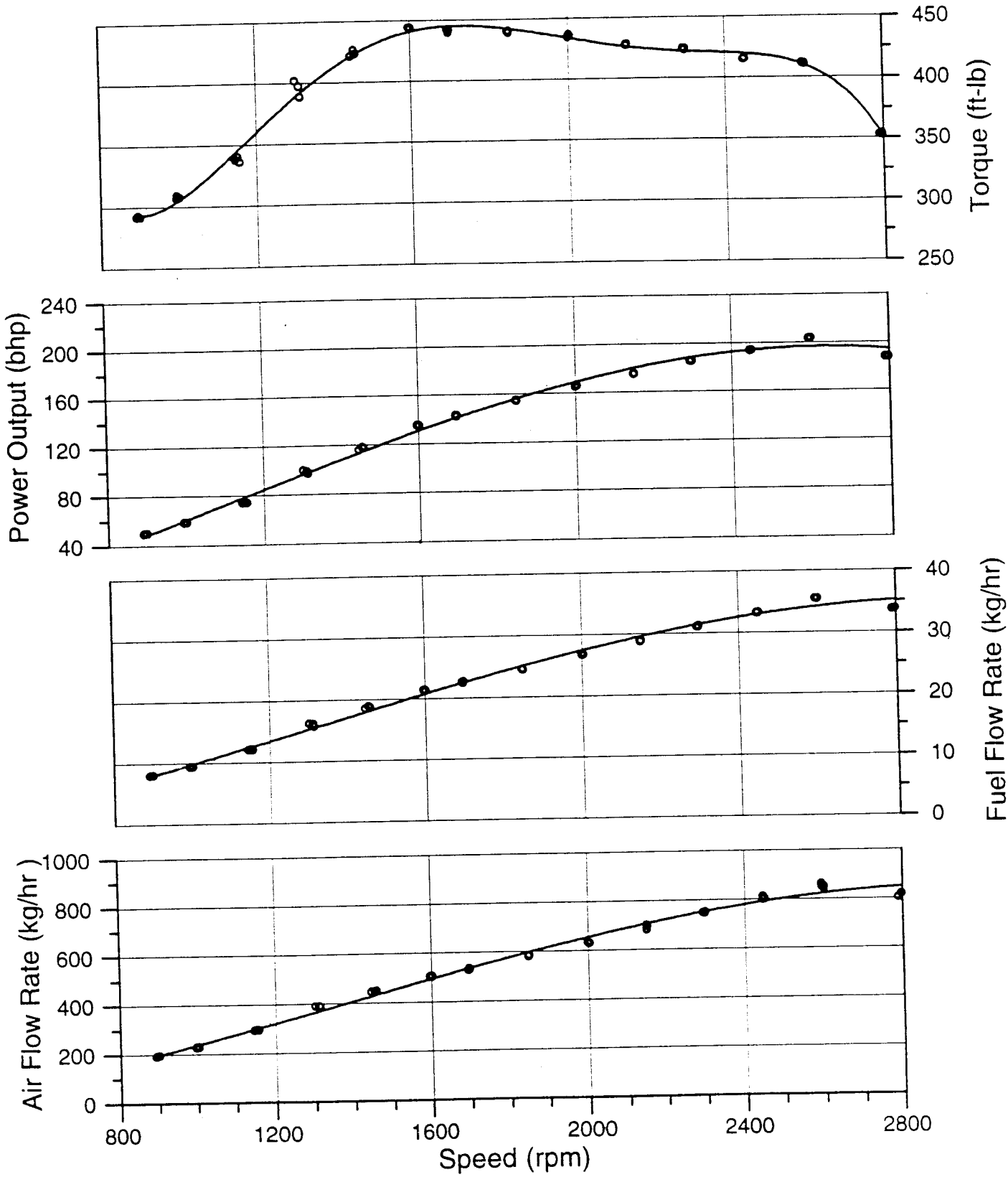
	Speed (rpm)	Torque (ft-lb)	Power (bhp)	Relative Change to the Specification
rated	2600	411	203	+4.1%
peak torque	1600	444	135	+5.5%

Activities/Tasks Conducted (cont'd)
Period: 98/03/30 to 98/04/05

3. Dynamometer and throttle controller tuning was commenced for transient cycle regression. Additional torque curve will be run to confirm the engine performance. Cummins will be consulted for acceptance of engine performance.
4. As informed by ADEPT, AERIFORM shipped LPG fuel to ORTECH on April 3. ORTECH will confirm with ADEPT the receipt of the fuel.

Activities/Tasks Planed Period: 98/04/06 to 98/04/12	Activities/Tasks Planed (cont'd) Period: 98/04/06 to 98/04/12
The following items will be completed: • Dynamometer and throttle controller for transient cycle regression • Spark timing measurement system setup • Emission tunnel conditioning for PM • Emission analyzer calibration for gaseous emissions • Quality control setup and preliminary sample range setup on GC for speciation analysis	• Preliminary engine emission test on certification LPG for emission confirmation • ORTECH will be closed for statuary holiday on April 10, 1998.

Figure 1: Engine Performance Curve (mtor837)



ORTECH

PROGRESS REPORT

Date: 4/13/98
Report: #4, Period: 98/04/06 to 98/04/12
ADEPT / Cummins B5.9 LPG **Attn: Mr. Alex Spataru**

To:	Mr. Alex Spataru
Client:	ADEPT Group Inc.
Project:	**ADEPT / Cummins B5.9 LPG**
Tel:	(310) 478-8448
Fax:	(310) 478-5658
ADEPT P.O.:	Date: March 2,1998, Value: US$141,350
ORTECH Ref:	Project No.: 1-05-01-01-11516 Proposal No.: 97-1-05-01-01-P8138-FI
Submitted by:	Dr. Aurobindo Das
Telephone:	(905) 822-4111 (X418)
Fax:	(905)823-1446

Estimated Testing Completion Date:	To be determined
Estimated Project Expenditure to 98/04/12:	US$29,500
Estimated Expenditure for Last Week (Apr.06-Apr.12):	US$5,400
Estimated Cost at Completion:	To be determined
Initial Payment received:	US$15,000
Invoiced to date:	
Invoice details:	
Received to date:	

Activities/Tasks Conducted Period: 98/04/06 to 98/04/12	Activities/Tasks Conducted (cont'd) Period: 98/04/06 to 98/04/12
1. The following items were completed: • Spark timing measurement system setup • Additional torque curve and two point power check • Emission analyzer calibration for gaseous emissions 2. Dynamometer and throttle controller tuning was completed for transient cycle regression. The engine is able to pass cycle regression criteria with 20 ft-lb of curb idle transmission torque.	3. Cummins was consulted for the acceptance of engine performance. The acceptable performance is in a range of ±5% specification. 4. ORTECH has not received LPG fuel from AERIFORM, although ADEPT had noted that AERIFORM promissed to ship the fuel to ORTECH on April 3.

Activities/Tasks Planed Period: 98/04/13 to 98/04/19	Activities/Tasks Planed (cont'd) Period: 98/04/13 to 98/04/19
The following items will be completed: • Emission tunnel conditioning for PM • Preliminary engine emission test on certification LPG for emission confirmation	• Quality control setup and preliminary sample range setup on GC for speciation analysis

Engine daily performance check:

Date	Run #	Speed rpm	Observed Torque ft-lb	Observed Power hp	Corrected Torque ft-lb	Corrected Power hp
98/04/07	859	2600	425.5	210.7	416.7	206.3
		1600	448.9	136.5	439.8	133.8
98/04/08	868	2600	421.1	207.9	412.1	203.5
		1600	448.8	136.4	439.2	133.5
98/04/09	871	2600	421.1	207.9	418.3	206.5
		1600	448.8	136.4	445.9	135.5
98/04/13	882	2600	413.6	204.5	406.2	200.9
		1600	440.2	133.8	432.4	131.4
98/04/14	889	2600	413.3	204.4	413.1	204.3
		1600	442.9	134.8	442.7	134.7
98/04/15	904	2600	404.0	199.8	402.2	199.0
		1600	436.2	132.9	434.3	132.3

Cummins specified engine performance:

Condition	Speed (rpm)	Torque (ft-lb)	Power (hp)
Rated	2600	394 ±5% (ie. 374.3 to 413.7)	195 ±5% (ie. 185.3 to 204.8)
Peak torque	1600	420 ±5% (ie. 399 to 441)	128 ±5% (ie. 121.6 to 134.4)

Y. Tao 4/15/98

Table 1: Effect of ECU Supply Voltage Change on Engine Power

run# 913;	date: 98/04/16	fuel: HD5	
ECU supply voltage	**observed power**	**observed torque**	**rated speed**
(volt)	**(bhp)**	**(ft-lb)**	**(rpm)**
12	187.5	379.1	2600
12.3	190.1	383.9	2600
12.6	190.9	385.7	2600
12.9	193.8	391.5	2600
13.2	194.6	393.3	2600
13.5	197.0	397.9	2600
13.8	198.1	400.3	2600
14.1	201.1	406.3	2600

Table 2: Effect of ECU Supply Voltage Change on Engine Transient Emissions
(April 16, 1998; certification LPG fuel)

run #	description	ECU voltage	cycl power	THC	CO	NOx	CO2
		(volt)	(hp-hr)	(g/hp-hr)	(g/hp-hr)	(g/hp-hr)	(g/hp-hr)
909	hot cycle	13.6	12.19	0.711	0.209	3.29	666
916	hot cycle	12.6	12.05	0.953	0.181	2.57	677
922	hot cycle	12.4	11.64	0.868	0.187	2.45	684

Y.Tao

4/17/98

ORTECH

PROGRESS REPORT

Date: 4/20/98
Report: #5, Period: 98/04/13 to 98/04/19
ADEPT / Cummins B5.9 LPG **Attn: Mr. Alex Spataru**

To:	Mr. Alex Spataru	**Estimated Testing Completion Date:**	To be determined
		Estimated Project Expenditure to 98/04/19:	US$36,900
Client:	ADEPT Group Inc.	**Estimated Expenditure for Last Week (Apr.13-Apr.19):**	US$7,400
Project:	**ADEPT / Cummins B5.9 LPG**	**Estimated Cost at Completion:**	To be determined
Tel:	(310) 478-8448	**Initial Payment received:**	US$15,000
Fax:	(310) 478-5658	**Invoiced to date:**	US$19,194.53
ADEPT P.O.:	Date: March 2,1998, Value: US$141,350	**Invoice details:**	#107761 (Apr.16,1998)
ORTECH Ref:	Project No.: 1-05-01-01-11516	**Received to date:**	NO
	Proposal No.: 97-1-05-01-01-P8138-FI		

Submitted by: Dr. Aurobindo Das
Telephone: (905) 822-4111 (X418)
Fax: (905)823-1446

Activities/Tasks Conducted
Period: 98/04/13 to 98/04/19

1. The following items were completed:
   - Emission tunnel conditioning for PM
   - Emission analyzer calibration for gaseous emissions
   - Daily engine performance check for last two weeks
2. Dynamometer and throttle controller was further tuned for transient cycle regression. The engine is able to pass cycle validation criteria with 10 ft-lb of curb idle transmission torque.
3. Daily engine performance checks (Observed torque and power) for past two weeks were corrected to Cummins Standard Conditions. Corrected torque and power of the most recent runs (all runs this week) were will within ±5% of specifications. Results discussed with ADEPT / Cummins accepted.
4. Preliminary engine emission tests were done on HD5. Sample results is as follows:

	run#	NOx	THC	CO
cold cycle:	900	2.549	1.633	0.600
hot cycle #1:	901	2.382	0.969	0.199
hot cycle #2:	902	2.405	1.079	0.168

where: a) units is g/bhp-hr; b) ECU supply voltage was 12.3 volt.

Activities/Tasks Conducted (cont'd)
Period: 98/04/13 to 98/04/19

5. Compositions of HD5 fuel used are as follows:
   Propane: 96%; Ethane: 4%; Air: <DL; Butane: <DL.
6. During test runs, it was found that the engine power and emissions were sensitive to: a) ECU supply voltages; b) throttle sensitivities. Summary of engine power and emissions vs. ECU voltages was sent to ADEPT for review. ORTECH is pending for the decision on ECU voltage setting.
7. As of 17th April 1998, ORTECH had not received LPG fuel from AERIFORM, although ADEPT had noted that AERIFORM promised to ship the fuel to ORTECH on April 3. As ADEPT agreed, ORTECH will charge ADEPT US$150/day starting from 7th April.
8. Quality control setup and preliminary sample range setup on GC for speciation analysis were commenced.

Activities/Tasks Planed Period: 98/04/20 to 98/04/26	Activities/Tasks Planed (contend) Period: 98/04/20 to 98/04/26
The following items will be completed: • Quality control setup and preliminary sample range setup on GC for speciation analysis • Receiving LPG fuel from AERIFORM.	• Transient emission facility will be occupied by another project. No emission tests will be conducted. No facility charge until test resumes.

ORTECH

PROGRESS REPORT

Date: 4/27/98
Report: #6, Period: 98/04/20 to 98/04/26
ADEPT / Cummins B5.9 LPG Page 1 **Attn: Mr. Alex Spataru**

To:	Mr. Alex Spataru	**Estimated Testing Completion Date:**	To be determined
		Estimated Project Expenditure to 98/04/19:	US$38,400
Client:	ADEPT Group Inc.	**Estimated Expenditure for Last Week (Apr.13-Apr.19):**	US$1,500
Project:	**ADEPT / Cummins B5.9 LPG**	**Estimated Cost at Completion:**	To be determined
Tel:	(310) 478-8448	**Initial Payment received:**	US$42,000
Fax:	(310) 478-5658	**Invoiced to date:** US$19,194.53	
ADEPT P.O.:	Date: March 2,1998, Value: US$141,350	**Invoice details:** #107761 (Apr.16,1998)	
ORTECH Ref:	Project No.: 1-05-01-01-11516	**Received to date:** NO	
	Proposal No.: 97-1-05-01-01-P8138-FI		

Submitted by: Dr. Aurobindo Das
Telephone: (905) 822-4111 (X418)
Fax: (905)823-1446

Activities/Tasks Conducted Period: 98/04/20 to 98/04/26	Activities/Tasks Conducted (cont'd) Period: 98/04/20 to 98/04/26
1. As of 27th April 1998, ORTECH had not received LPG fuel from AERIFORM, although ADEPT had noted that AERIFORM promised to ship the fuel to ORTECH on April 3. As ADEPT agreed, ORTECH will charge ADEPT US$150/day starting from 7th April. 2. As of 27th April 1998, ORTECH had not received any notice on the ECU voltage setting.	3. Quality control setup and preliminary sample range setup on GC for speciation analysis were continued. Unexpected problems on GC analyzer were experienced and were expected to be resolved in next week. 4. No engine test was conducted in test cell.

Activities/Tasks Planed Period: 98/04/27 to 98/05/02	Activities/Tasks Planed (contend) Period: 98/04/26 to 98/05/02
The following items will be completed: • Quality control setup and preliminary sample range setup on GC for speciation analysis • Waiting for LPG fuel from AERIFORM.	• Pending for the notice on ECU voltage setting. • Pending for Amendment Authorization #1 to be signed.